The Rational Method

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Before calculating the sizes of intakes and pipes or determining their final locations, the designer must estimate how much water is discharged into each intake or culvert inlet. The calculation used for this is referred to as "The Rational Method," and it depends primarily on the following formula:

$$Q = CIA \text{ English units} \qquad\qquad Q = \frac{CIA}{K} \text{ metric units}$$

where:

Q = an estimate of the peak rate of runoff, measured in cubic feet (meters) per second

C = the fraction of rainfall that appears as surface runoff from the drainage area (the ratio of surface runoff to rainfall)

I = the average rainfall intensity, measured in inches (millimeters) per hour

A = the drainage area, measured in acres (hectares) (the area of land that drains into a given intake or culvert inlet)

K = 360

The average rainfall intensity (I) is the most unwieldy factor in the calculation. "I" is based on values of T_c and T, where:

T_c = the rainfall intensity averaging time (measured in minutes), usually referred to as the "time of concentration." T_c is the time required for water to flow from the hydraulically most distant point in the watershed (drainage area) to the intake or culvert inlet.

T = the recurrence interval (or design frequency). T represents the severity of the storm (i.e., once every 2 years, 10 years, etc.) for which a given drainage area is designed.

The Rational Method generally assumes a worst case scenario for a given recurrence interval. That is, the storm sewer is designed for conditions created by the worst storm expected during the recurrence interval. The Rational Method depends on a number of other assumptions as well. Factors that affect the results obtained by The Rational Method are discussed at the end of this section.

Drainage Area (A)

The area (A) is the drainage area, measured in acres (hectares). The drainage area is defined as the combined area of all surfaces that drain into a given intake or culvert inlet. The following are some points the designer should consider when determining a drainage area:

- How are individual lots graded? Rear to front, half to rear?
- Will the existing contour lines remain the same, or will the area be regraded?
- Which way will water run down the gutters of the streets?
- At intersections, will the water turn the corner or flow across the intersection?
- Will water run the same direction for all rainfall intensities?

Using a plan sheet or drainage map, draw the drainage area for each intake. Any of the following may be useful in determining the correct area:

- USGS topographic maps
- Aerial photos
- Contour maps
- Drainage maps
- Cross sections
- Field reviews

The designer should be certain to measure the drainage area *in acres (hectares)* using planimeters or scales.

Runoff Coefficient (C)

The runoff coefficient (C), also called the "coefficient of imperviousness," is a unitless value representing the ratio of runoff to rainfall. Factors that contribute to C are related to the condition of the land, what is on the land, and the character of the rainfall. The following factors have been identified by various experts. In some cases, they overlap.

- Character of the soil
- Shape of the drainage area
- Previous moisture conditions
- Slope of the watershed
- Amount and type of surface storage
- Percentage of impervious surface
- Land use
- Interception by vegetation or animal life
- Amount of roof drainage
- Duration of rainfall
- Intensity of rainfall
- Recurrence interval (design frequency)

The actual ratio of runoff to rainfall is probably impossible to determine. However, several authors have published tables of C values based on the type of area in question. We reproduce these as Tables 1, 2, and 3. Normally, the designer should decide the appropriate value of C for each drainage area using these tables. However in some cases, special concern for high intensity rainfall (i.e., a 100-year recurrence interval) may warrant the use of Figure 1 (on page 4), which suggests C values based on not only the imperviousness of the land, but also on the intensity of rainfall expected.

Table 1: Runoff coefficients.[1]

description of area	runoff coefficients
Business:	
downtown areas	0.70–0.95
neighborhood areas	0.50–0.70
Residential:	
single-family areas	0.30–0.50
multi-units, detached	0.40–0.60
multi-units, attached	0.60–0.70
residential (suburban)	0.25–0.40
apartment dwelling areas	0.50–0.70
Industrial:	
light areas	0.50–0.80
heavy areas	0.60–0.90
parks, cemeteries	0.10–0.25
playgrounds	0.20–0.35
railroad yard areas	0.20–0.40
unimproved areas	0.10–0.30

Table 2: Runoff coefficients.[2]

type of drainage area	runoff coefficients
concrete and bituminous pavements	0.70–0.95
gravel and macadam surfaces	0.40–0.70
impervious soil	0.40–0.65
impervious soils with turf*	0.30–0.55
slightly pervious soils*	0.15–0.40
pervious soils*	0.05–0.10
wooded areas (depending on slope and cover)	0.05–0.20

* For slopes from 1 to 2 percent

[1] American Concrete Pipe Association, *Concrete Pipe Design Manual* (Arlington, Virginia, 1970).

[2] Ritter and Paquette, *Highway Engineering* (New York, The Ronald Press Co., 1951).

Table 3: Runoff coefficients.[3]

character of surface	runoff coefficients
Streets:	
asphaltic	0.70–0.95
concrete	0.80–0.95
brick	0.70–0.85
drives and walks	0.75–0.85
roofs	0.75–0.95
Lawns (sandy soil):	
flat, 2%	0.05–0.10
average, 2% - 7%	0.10–0.15
steep, 7%	0.15–0.20
Lawns (heavy soil)	
flat, 2%	0.13–0.17
average, 2% - 7%	0.18–0.22
steep, 7%	0.25–0.35

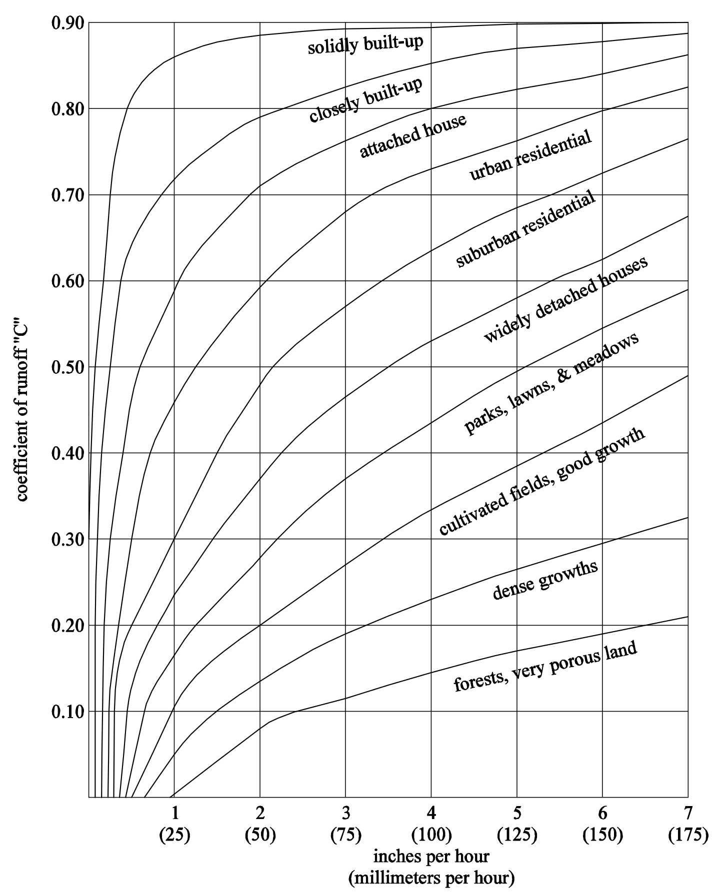

Figure 1: Runoff coefficient vs. intensity for varying imperviousness.[4]

[3] ASCE-WPCF, "Design and Construction of Sanitary and Storm Sewers," *ASCE Manuals and Reports on Engineering Practice No. 37* (New York, 1969).

[4] Ordon, C.J., "A Modified Rational Formula for Storm Sewer Runoff," *Water and Sewage Works* (June 1954) vol. 101, 275-277.

For urban design, the designer should try to select one value of C that best describes a given drainage area. In fact, it may be that one C value adequately describes an entire project. However, when a single drainage area is composed of distinct parts with different runoff coefficients, the designer may use a weighted average to find a composite C. The equation used for this average is:

$$C = \frac{(C_1 A_1 + C_2 A_2 + C_3 A_3 ... + ... C_n A_n)}{\text{total area}}$$

where A_1, A_2, A_3, and A_n are the areas of the distinct parts and C_1 is the C value for A_1, C_2 is the C value for A_2, and so on. If there is a large deviation in values of C for a given drainage area or if there are separate drainage areas with different outlet storm sewers, separate C values for each area may be used.

Rainfall Intensity, I

The rainfall intensity (I), measured in inches (millimeters) per hour, is the average rainfall intensity that is expected to fall on a drainage area over the duration of a storm. The designer determines "I" from:

- the recurrence interval (T), measured in years, and
- the storm duration, measured in minutes.

The Rational Method uses the time of concentration (T_c), discussed below, as the storm duration.

Recurrence Interval, T

The recurrence interval (T) varies for each element of a storm sewer system, depending on how vital it is to avoid flooding in the area being drained. The recurrence interval is therefore selected using the following guidelines.

- 2-year interval: Used for the design of intakes and the spread of water on the pavement for primary highways and city streets.
- 10-year interval: Used for the design of intakes and the spread of water on the pavement for freeways and interstate highways. Also used for the design of smaller storm sewer pipe on most lateral, branch, and longitudinal lines.
- 25-year interval: Used for the design of major storm sewer lines (48- inch or 1200-millimeter diameter and above).
- 50-year interval: Used for the design of subways (underpasses) and sag vertical curves where storm sewer pipe is the only outlet. Also used for depressed freeway sections and for high liability areas.

100-year interval: Used for the major storm check on all projects.

Time of Concentration, T_c

The time of concentration (T_c) is defined as the time it takes for runoff to travel from the hydraulically most distant point in a drainage area to a point of reference downstream (the intake or culvert). The Rational Method assumes that the peak runoff rate occurs when the rainfall intensity (I) lasts as long or longer than T_c. T_c is therefore used as the storm duration and must be estimated for each drainage area as a part of selecting the appropriate value of "I." When using the equations and charts in this section, do not use a value of T_c less than 5 minutes. T_c for intakes normally consists of at least two components:

1. T_c (overland flow)
2. T_c (gutter flow)

The designer should add a third component if overland flow is channelized (i.e., streams, ditches, paved ditch liners, etc.) upstream from the location where the flow enters the highway gutter. However, T_c (overland flow) is usually the only significant component, and in most cases the other two components can be ignored. The following procedures describe how to determine T_c (overland flow). If T_c (gutter flow) is significant, it is calculated separately and added to T_c (overland flow) to get the total. Procedures for calculating T_c (gutter flow) are given later in this section.

T_c (Overland Flow)

The most accurate description of T_c (overland flow) (hereafter referred to as T_c) is generally considered to be the kinematic wave equation. The overland flow component of the kinematic wave equation is shown below.

$$T_c = \frac{(K)(L)^{0.6}(n)^{0.6}}{(I)^{0.4}(S)^{0.3}}$$

where:

T_c = time of concentration (overland flow), measured in minutes

L = overland flow length, measured in feet (meters)

n = Manning roughness coefficient (see Figure 3, page 12)

I = rainfall intensity rate, measured in inches (millimeters) per hour

S = the average slope of the overland area

K = .933 (6.943 for metric units)

The kinematic wave theory is consistent with the latest concepts of fluid mechanics, and it considers all those parameters found important in overland flow when the flow is turbulent (where the product of the rainfall intensity, I, and length of the slope, L, is in excess of 500 for English units and 3870 for metric units).

Determining T_c and "I" (preferred method, English units only)

The preferred method for determining T_c (and hence "I") uses a nomograph (shown in Figure 2) for the solution to the kinematic wave equation. The method involves a trial and error procedure, wherein the designer first guesses a value of "I" and uses it in Figure 2 to determine a value of T_c. The values of "I" and T_c are then checked against the appropriate value found in Table 5 (pages 17 through 20), using the recurrence interval (T) chosen for the particular problem. The designer should repeat the procedure until the "I" that is used produces close agreement in the values of T_c found in Table 5. This procedure is illustrated in Example 1.

Example 1

Given:

Overland flow length: L = 150 ft

Average slope: S = 0.02

Manning coefficient: n = 0.4 (grass, see Figure 3)

Recurrence interval: T = 10 years

Location: Keokuk, Iowa

Find: "I"

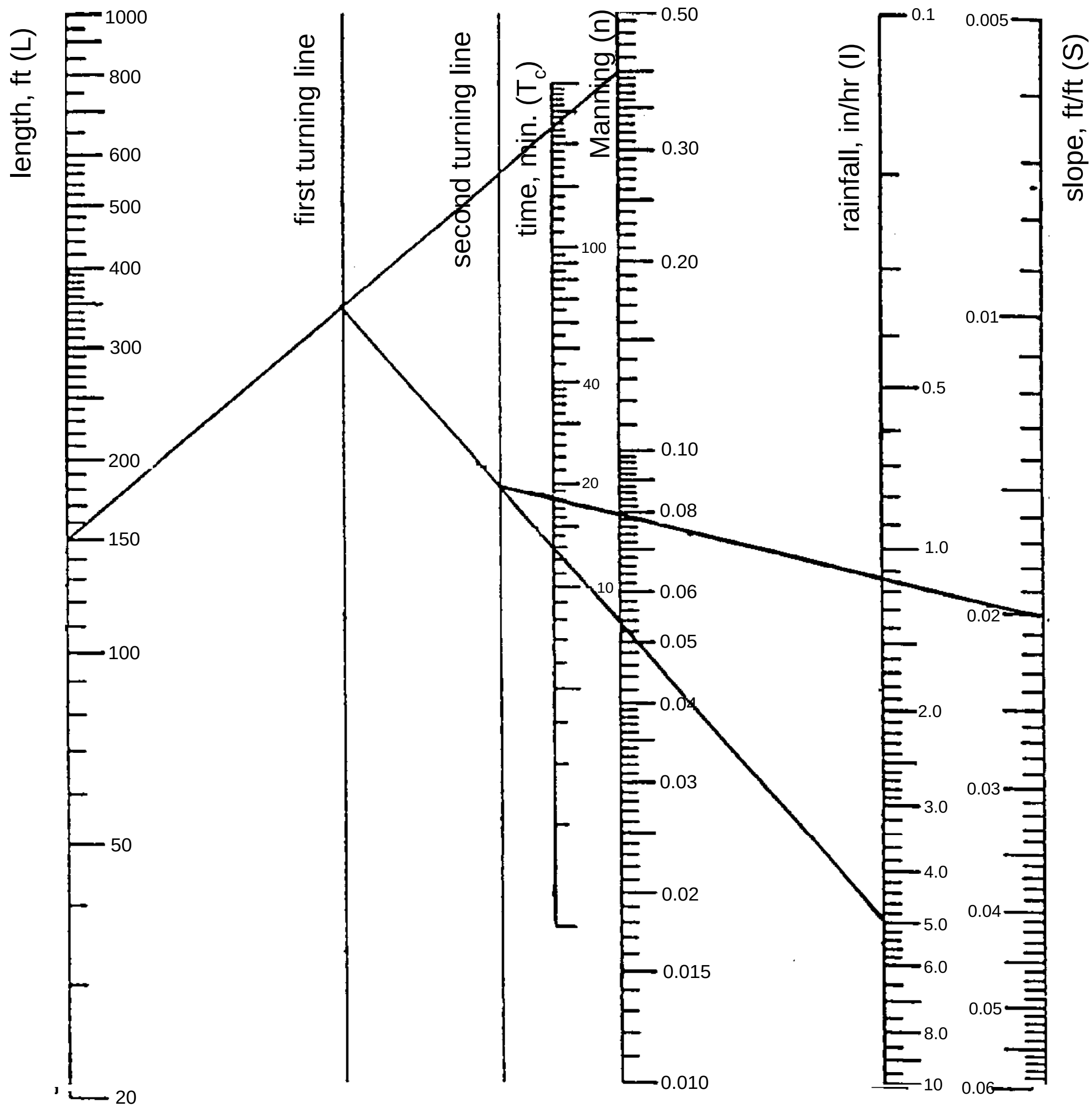

Figure 2: Nomograph for determining time of concentration for overland flow, Kinematic Wave Formulation.[5]

Solution to Example 1:

1. Use the nomograph in Figure 2, as follows:

    a. Draw a line from “L = 150” on the length scale to “n = 0.4” on the Manning scale.
    b. Find the point where this line crosses the first turning line. This is the first turning point.
    c. Guess a value of “I” (5 inches/hour).
    d. Draw a line from the first turning point to “I = 5” on the rainfall scale.
    e. Find the point where this line crosses the second turning line. This is the second turning point.
    f. Draw a line between the second turning point and “S = 0.02” on the slope line.
    g. Read the value of T_c (18 minutes) where the last line you drew crosses the time line.

[5] FHWA, *Design of Urban Highway Drainage* (1979).

2. Determine the appropriate climatic Sectional Code the geographical area (pages 19 and 20 for Keokuk) and use it as follows:
   a. Keokuk is located in Southeast Iowa; the Sectional Code is 09. Choose the current interval column T for the problem (T = 10 years).
   b. Convert the rainfall in inches to intensity in inches per hour by dividing the rainfall in inches by the duration in hours. This produces the table below for Sectional Code 09.

section	Duration (min.)	10-year (I= inches)	Intensity (in/hr)
09	5	0.56	6.7
09	10	0.98	5.9
09	15	1.26	5.0
09	30	1.73	3.5
09	60	2.19	2.19
…	…	…	…

   c. Find the appropriate rainfall intensity (I = 5 in/hr) and select the according time of concentration (T_c = 15min).
3. Compare T_c from the nomograph (18 minutes) and T_c from the table (15 minutes). Since they do not match, try the procedure again for a different value of "I."
   a. Try I = 4.25 in/hr
   b. This produces values of:
      T_c = 22 from the nomograph (Figure 2)
      T_c = 22 from the table above (using interpolation)
   c. I = 4.25 in/hr produces close agreement between the nomograph and the interpolated value from the table. Assume "I" is 4.25 in/hr and T_c is 22 minutes.

When using the nomograph, the designer should use Manning roughness coefficients of n = 0.013 for concrete and n = 0.40 for grass. These values closely agree with normal flow data. Manning coefficients for other surfaces may be obtained from flow experiments. See Figure 3 on the page 12 for other values of the coefficient.

Determining T_c and "I" (trial and error)

To determine T_c (and hence "I") for metric units, a trial and error procedure is used, wherein the designer first guesses a value of "I" and uses it in the equation to determine a value of T_c. The values of "I" and T_c are then checked against the appropriate value in Table 6 (found on pages 21 through 24), using the recurrence interval (T) chosen for the particular problem. The designer should repeat the procedure until the "I" that is used produces close agreement in the values of T_c obtained from the equation and Table 6. This procedure is illustrated in Example 2.

Example 2

Given:

Overland flow length: L = 45.7 m

Average slope: S = 0.02

Manning coefficient: n = 0.4 (grass, see Figure 2)

Recurrence interval: T = 10 years

Location: Keokuk, Iowa

Find: "I"

Solution:

1. Use the overland flow component of the kinematic wave equation to determine T_c.
   Guess a value of "I" (125 mm/h) to initially solve for T_c.

$$T_c = \frac{(6.943)(45.7)^{0.6}(0.4)^{0.6}}{(125)^{0.4}(0.02)^{0.3}} = 18.6 \text{ min.}$$

Determine the appropriate climatic Sectional Code for the geographical area (page 24 for Keokuk) and use it as follows:

a. Keokuk is located in Southeast Iowa; the sectional Code is 09. Choose the current interval column T for the problem (T = 10 years).
b. Convert the rainfall in millimeters to intensity in millimeters per hour b dividing the rainfall in millimeters by the duration in hours. This produces the table below for Sectional Code 09.

section	Duration (min.)	10-year (I= mm.)	Intensity (mm/hr)
09	5	14.22	170
09	10	24.89	149
09	15	32.00	128
09	30	43.94	87.8
09	60	55.63	55.6
…	…	…	…

c. Find the appropriate rainfall intensity (I = 125mm/h) and get the according time of concentration from the above table. By interpolation: ((30-15)/(87.8-128))*(125-128)) +15 = 16.1 min.

2. Compare T_c from the equation (18.6 minutes) and T_c from the Table (16.1 minutes). Since they do not match, try the procedure again for a different value of "I."

   a. Try I = 116.5 mm/hr
   b. Get values of:
      T_c = 19.1 from the equation
      T_c = 19.3 from the table (using interpolation)
   c. I = 116 mm/hr produces close agreement between the results of the equation and the interpolated value from the table. Assume "I" is 116 mm/hr and T_c is 19 minutes.

See Figure 3 for Manning values of the coefficient. Manning coefficients for surfaces other than the ones shown may be obtained from flow experiments.

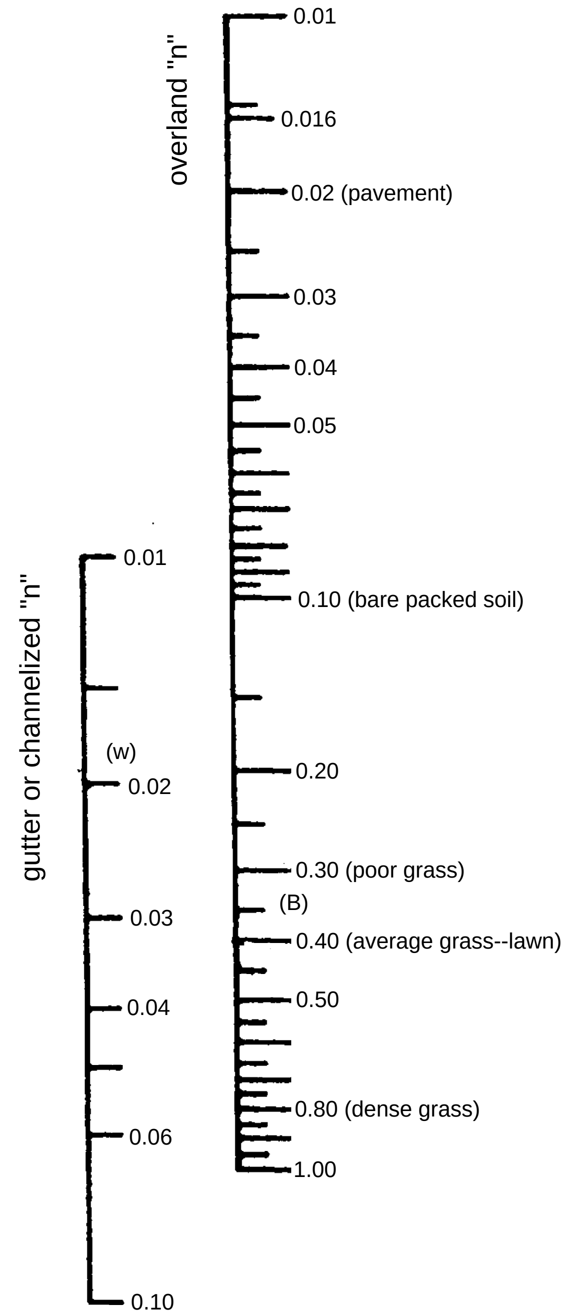

Figure 3: Manning roughness coefficient (n).

Determining T_c and "I" (other methods)

Two other methods are commonly used to find the time of concentration (T_c) in urban areas: the Kirpich formula and the Kerby formula. After using either formula to calculate T_c, the designer should then use Table 5 to determine "I."

The Kirpich formula is the most commonly used formula for estimating T_c in both urban and rural areas. According to Kirpich,

$$T_c = 0.0078\left(\frac{L}{S^{0.5}}\right)^{0.77} \quad \text{English units} \qquad T_c = 0.0078\left(\frac{3.2808L}{S^{0.5}}\right)^{0.77} \quad \text{metric units}$$

where:

T_c = time of concentration (overland flow), measured in minutes

L = length of travel, measured in feet

S = slope—the difference in elevation between the intake and the most remote point divided by the length (L)

For English units, this produces the nomograph shown in Figure 4.

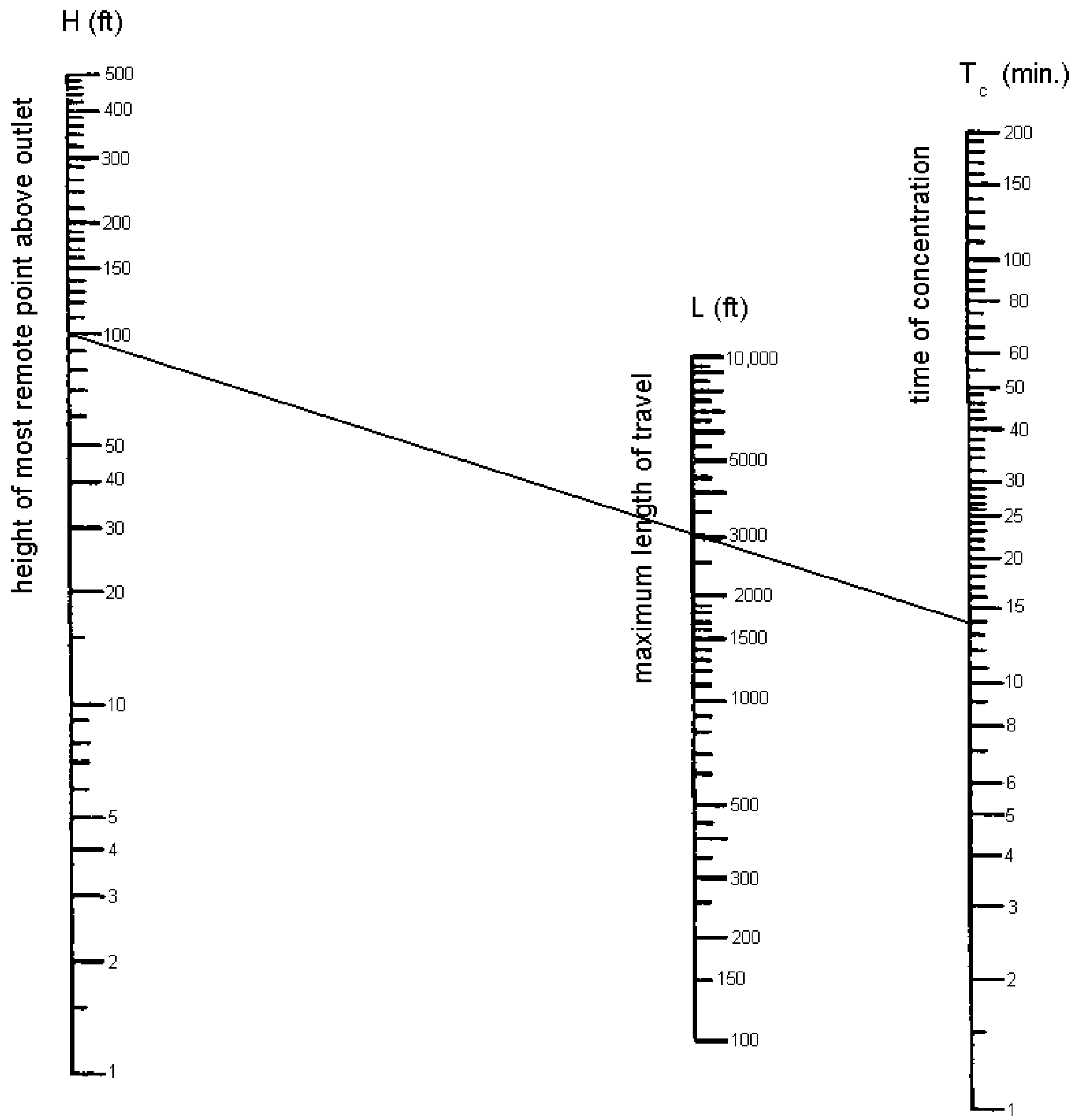

Figure 4: Nomograph for T_c using the Kirpich formula.[6]

Example 3 demonstrates the use of this nomograph.

[6] Kirpich, P.Z., *Civil Engineering*, Vol.10, No. 6, (June 1940) 362.

Example 3

H = 100’

L = 3000’

Using the given information, S = $\dfrac{100-0}{3000}$ = 0.0333

Then T_c = $0.0078\left(\dfrac{3000}{.0333^{0.5}}\right)^{0.77}$ = 13.75 min. (use 14 min.).

Using the nomograph, draw a straight line from H = 100 on the height scale to L = 3000 on the length scale. Extend this line to the time of concentration scale (see Figure 4) and determine where it crosses (about 14 min.). This is the time of concentration, T_c.

Because of the database that was used, some authors suggest that the following modifications be made to the value of T_c estimated by the Kirpich formula.

- Use T_c from the equation for natural basins with well-defined channels, for overland flow on bare earth, and for mowed-grass roadside ditches.
- Multiply T_c by 2 for overland flow, grassed channels.
- Multiply T_c by 0.4 for overland flow, concrete or asphalt surfaces.
- Multiply T_c by 0.2 for concrete channels.

Another formula that is used is Kerby (1959). Kerby’s formula is based on the drainage of military airfields. T_c (Kerby) is for overland flow only. If channelized flow occurs in a drainage area, the time of concentration will be the time of the overland flow plus the time in the channel.

According to Kerby,

$$T_c = 0.83\left(\frac{N \times L}{S^{0.5}}\right)^{0.467} \quad \text{English units} \qquad T_c = 0.83\left(\frac{N \times 3.2808L}{S^{0.5}}\right)^{0.467} \quad \text{metric units}$$

where:

T_c = time of concentration (overland flow), measured in minutes

L = length from the extremity of the drainage area (in a direction parallel to the slope) to the location of a defined channel, measured in feet (meters)

S = slope—the difference in elevation between the extreme edge of the drainage area and the point in question divided by the horizontal distance between the two points

N = 0.02 for smooth impervious surfaces
0.10 for smooth bare packed soil, free of stones
0.20 for poor grass, cultivated row crops, or moderately rough bare surfaces
0.40 for pasture or average grass cover
0.60 for deciduous timberland
0.80 for conifer timberland with deep forest litter or dense grass cover

T_c (Gutter Sections)

Solving for the T_c component in gutter sections is also a trial and error procedure. The designer should use Manning’s Equation or the nomograph in Figure 2 of Section 4A-5 to calculate Q for the gutter section. Q is then divided by the cross-sectional area to calculate velocity and determine the approximate time in the gutter. Unless the water is carried in the gutter for a long distance, the T_c in the gutter will be a very small part of the total T_c for the drainage area.

Normally, the largest part of the distance to the intake is overland, with little time spent in the gutter. The time of flow in the gutter is insignificant unless it is a minute or more, and can normally be ignored.

The Basis for Calculating "I"

Rainfall intensities are shown in Table 5 and 6, Sectional Mean Frequency Distribution for Storm Periods of 5 Minutes to 10 days and Recurrence Interval of 2 Months to 1000 Years in Iowa. The Climatic Sectional Codes for Iowa are shown in Figure 5. Rainfall intensities for any duration and recurrence interval at any location in Iowa can also be determined from the following equation:

$$I = \frac{aT^m}{(T_c + b)^n} \text{ English units} \qquad I = 25.4\left[\frac{aT^m}{(T_c + b)^n}\right] \text{ metric units}$$

where:

I = rainfall intensity, measured in inches (millimeters) per hour

T = recurrence interval, measured in years

T_c = storm duration, measured in minutes

a, b, m, and n = coefficients shown in Table 4

Table 4: Coefficients for rainfall intensity equation.

location	a	b	m	n
Charles City	33	10	0.180	0.775
Davenport	47	15	0.184	0.824
Des Moines	57	18	0.179	0.852
Dubuque	43	12	0.204	0.817
Keokuk	48	14	0.192	0.828
Omaha	42	13	0.221	0.821
Sioux City	50	14	0.208	0.849

The HYDRAIN computer system may also be used to determine "I." When using the HYDRO program on the HYDRAIN system, IDF curves may be developed for different design storms (recurrence intervals). These curves should be saved for use during storm sewer design and analysis. See the HYDRAIN user manual for more information.

Some Things to Consider When Using the Rational Method

The Rational Method is based on a large number of assumptions. Thus, when evaluating results, the designer or engineer should consider how exceptions or other unusual circumstances might affect those results. The following are some factors that might not normally be considered, yet could prove important.

1. A storm sewer will be in place for 50 years, more or less, and will be subjected to whatever storms come along. The total system needs to be designed for all these storms at the least total cost.
2. The storm duration gives the length of time over which an average rainfall intensity (I) persists. Neither the storm duration nor "I" say anything about how the intensity varies during the storm, nor do they consider how much rain fell before the period in question.

3. A 20% variation in the value of C, up or down, has the same effect as changing a 5-year recurrence interval to a 15-year or a 2-year interval respectively.
4. The chance of all design assumptions being satisfied simultaneously is less than the chance that the rainfall rate used in the design will actually occur. This, in effect, creates a built-in factor of safety.
5. Another built-in factor of safety is the usual design practice of having the hydraulic grade line near the top of the pipe (or box). Since the top of the storm sewer pipe is always a few feet (about a meter) lower than the street elevation, a rainfall intensity greater than the intensity for which the sewer is designed does not automatically mean that flooding will occur.
6. A decided difference can exist between intense point rainfall (rainfall over a small area) and mean catchment area rainfall (average rainfall). This is particularly true for thunderstorms and for drainage areas greater than about 300 acres (120 hectares). For that reason the rational method should be applied to drainage areas less than 200 acres (80 hectares).
7. In an irregularly shaped drainage area, a part of the area that has a short time of concentration (T_c) may cause a greater runoff rate (Q) at the intake (or other design point) than the runoff rate calculated for the entire area. This is because parts of the area with long concentration times are far less susceptible to high-intensity rainfall. Thus, they skew the calculation.
8. A portion of a drainage area which has a value of C much higher than the rest of the area may produce a greater amount of runoff at a design point than that calculated for the entire area. This effect is similar to that described in item 7 above.

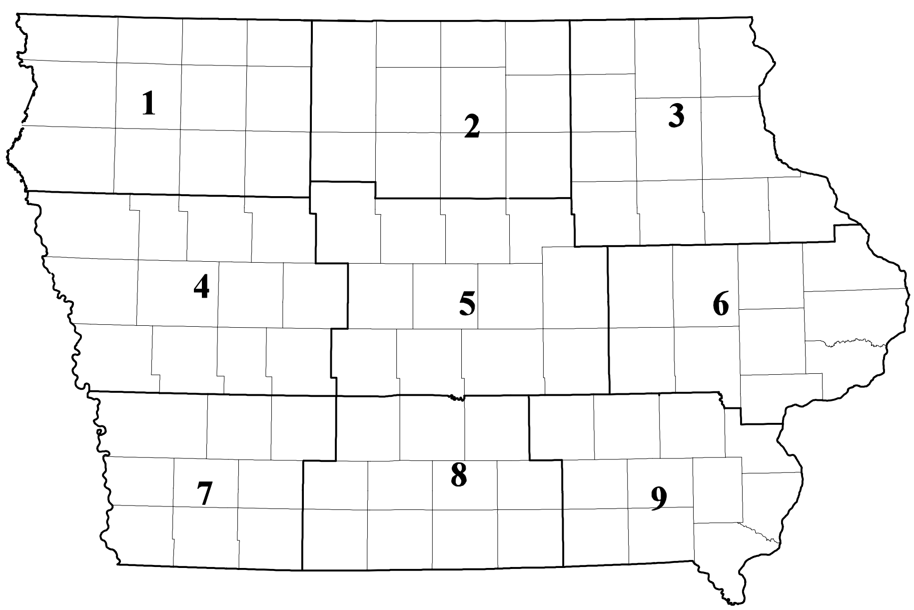

Figure 5 : Climatic Sectional Code for Iowa.

Table 5: Sectional Mean Frequency Distribution for Storm Periods of 5 Minutes to 10 Days and Recurrent Intervals of 2 Months to 100 Years in Iowa[7].

Rainfall (inches) for given recurrence interval T, return period in years.

*Sectional code (see Figure 5 Iowa map)

01-Northwest	04-West Central	07-Southwest
02-North Central	05-Central	08-South Central
03-Northeast	06-East Central	09-Southeast

*section	duration	2-year	5-year	10-year	25-year	50- year	100-year
01	10-day	4.81	5.84	6.70	8.02	9.11	10.31
01	5-day	3.77	4.68	5.43	6.61	7.60	8.75
01	72-hr	3.33	4.21	4.99	6.07	7.12	8.23
01	48-hr	3.01	3.81	4.52	5.60	6.53	7.52
01	24-hr	2.75	3.50	4.14	5.11	5.97	6.92
01	18-hr	2.59	3.29	3.89	4.80	5.61	6.50
01	12-hr	2.39	3.05	3.60	4.45	5.19	6.02
01	6-hr	2.06	2.62	3.11	3.83	4.48	5.19
01	3-hr	1.76	2.24	2.65	3.27	3.82	4.43
01	2-hr	1.59	2.03	2.40	2.96	3.46	4.01
01	1-hr	1.29	1.64	1.95	2.40	2.81	3.25
01	30-min	1.02	1.30	1.53	1.89	2.21	2.56
01	15-min	0.74	0.95	1.12	1.38	1.61	1.87
01	10-min	0.58	0.73	0.87	1.07	1.25	1.45
01	5-min	0.33	0.42	0.50	0.61	0.72	0.83
02	10-day	5.04	6.26	7.32	8.93	10.37	11.40
02	5-day	4.13	5.05	5.80	7.00	8.03	9.28
02	72-hr	3.53	4.45	5.15	6.33	7.30	8.30
02	48-hr	3.30	4.11	4.78	5.80	6.67	7.67
02	24-hr	2.98	3.72	4.38	5.33	6.14	7.07
02	18-hr	2.80	3.50	4.12	5.01	5.77	6.65
02	12-hr	2.59	3.24	3.80	4.64	5.34	6.15
02	6-hr	2.24	2.79	3.29	4.00	4.61	5.30
02	3-hr	1.91	2.38	2.80	3.41	3.93	4.52
02	2-hr	1.73	2.16	2.54	3.09	3.56	4.10
02	1-hr	1.40	1.75	2.06	2.51	2.89	3.32
02	30-min	1.10	1.38	1.62	1.97	2.27	2.62
02	15-min	0.80	1.00	1.18	1.44	1.66	1.91
02	10-min	0.63	0.78	0.92	1.12	1.29	1.48
02	5-min	0.36	0.45	0.53	0.64	0.74	0.85
03	10-day	5.04	6.17	7.07	8.29	9.20	10.19
03	5-day	3.94	4.86	5.64	6.84	7.75	8.77
03	72-hr	3.44	4.33	5.14	6.19	7.00	7.84
03	48-hr	3.20	4.02	4.69	5.62	6.34	7.09
03	24-hr	2.91	3.67	4.31	5.11	5.73	6.36

*section	duration	2-year	5-year	10-year	25-year	50- year	100-year
03	18-hr	2.74	3.45	4.05	4.80	5.39	5.98
03	12-hr	2.53	3.19	3.75	4.45	4.99	5.53
03	6-hr	2.18	2.75	3.23	3.83	4.30	4.77
03	3-hr	1.86	2.35	2.76	3.27	3.67	4.07
03	2-hr	1.69	2.13	2.50	2.96	3.32	3.69
03	1-hr	1.37	1.72	2.03	2.40	2.69	2.99
03	30-min	1.08	1.36	1.59	1.89	2.12	2.35
03	15-min	0.79	0.99	1.16	1.38	1.55	1.72
03	10-min	0.61	0.77	0.91	1.07	1.20	1.34
03	5-min	0.35	0.44	0.52	0.67	0.69	0.76
04	10-day	5.22	6.31	7.16	8.24	9.21	10.27
04	5-day	4.06	4.94	5.74	7.04	8.13	9.27
04	72-hr	3.51	4.37	5.13	6.28	7.26	8.46
04	48-hr	3.16	3.97	4.71	5.86	6.81	7.82
04	24-hr	2.94	3.64	4.30	5.27	6.08	7.00
04	18-hr	2.76	3.42	4.04	4.95	5.72	6.58
04	12-hr	2.56	3.17	3.74	4.58	5.29	6.09
04	6-hr	2.20	2.73	3.23	3.95	4.56	5.25
04	3-hr	1.88	2.33	2.75	3.37	3.89	4.48
04	2-hr	1.71	2.11	2.49	3.06	3.53	4.06
04	1-hr	1.38	1.71	2.02	2.48	2.86	3.29
04	30-min	1.09	1.35	1.59	1.95	2.25	2.59
04	15-min	0.79	0.98	1.16	1.42	1.64	1.89
04	10-min	0.62	0.76	0.90	1.11	1.28	1.47
04	5-min	0.35	0.44	0.52	0.63	0.73	0.84
05	10-day	5.20	6.22	7.22	8.61	9.66	10.88
05	5-day	4.05	4.94	5.72	6.92	7.98	9.18
05	72-hr	3.47	4.41	5.16	6.22	7.06	8.12
05	48-hr	3.13	3.93	4.67	5.75	6.52	7.33
05	24-hr	2.91	3.64	4.27	5.15	5.87	6.61
05	18-hr	2.74	3.42	4.01	4.84	5.52	6.21
05	12-hr	2.53	3.17	3.71	4.48	5.11	5.75
05	6-hr	2.18	2.73	3.20	3.86	4.40	4.96
05	3-hr	1.86	2.33	2.73	3.30	3.76	4.23
05	2-hr	1.69	2.11	2.48	2.99	3.40	3.83
05	1-hr	1.37	1.71	2.01	2.42	2.76	3.11
05	30-min	1.08	1.35	1.58	1.91	2.17	2.45
05	15-min	0.79	0.98	1.15	1.39	1.58	1.78
05	10-min	0.61	0.76	0.90	1.08	1.23	1.39
05	5-min	0.35	0.44	0.51	0.62	0.70	0.79
06	10-day	5.21	6.27	7.12	8.25	9.27	10.35
06	5-day	4.12	4.89	5.61	6.70	7.75	9.00
06	72-hr	3.59	4.53	5.31	6.42	7.35	8.42
06	48-hr	3.21	4.15	5.05	6.02	6.87	7.83

*section	duration	2-year	5-year	10-year	25-year	50- year	100-year
06	24-hr	3.06	3.84	4.44	5.42	6.25	7.13
06	18-hr	2.88	3.61	4.17	5.09	5.88	6.70
06	12-hr	2.66	3.34	3.86	4.72	5.44	6.20
06	6-hr	2.30	2.88	3.33	4.07	4.69	5.35
06	3-hr	1.96	2.46	2.84	3.47	4.00	4.56
06	2-hr	1.77	2.23	2.58	3.14	3.62	4.14
06	1-hr	1.44	1.80	2.09	2.55	2.94	3.35
06	30-min	1.13	1.42	1.64	2.01	2.31	2.64
06	15-min	0.83	1.04	1.20	1.46	1.69	1.93
06	10-min	0.64	0.81	0.93	1.14	1.31	1.50
06	5-min	0.37	0.46	0.53	0.65	0.75	0.86
07	10-day	5.47	6.54	7.53	9.00	10.25	11.66
07	5-day	4.26	5.30	6.20	7.59	8.71	9.86
07	72-hr	3.85	4.79	5.56	6.78	7.80	8.99
07	48-hr	3.53	4.38	5.11	6.19	7.09	8.04
07	24-hr	3.22	3.93	4.57	5.56	6.45	7.28
07	18-hr	3.03	3.69	4.30	5.23	6.06	6.84
07	12-hr	2.80	3.42	3.98	4.48	5.61	6.33
07	6-hr	2.41	2.95	3.43	4.17	4.84	5.46
07	3-hr	2.06	2.52	2.92	3.56	4.13	4.66
07	2-hr	1.87	2.28	2.65	3.22	3.74	4.22
07	1-hr	1.51	1.85	2.15	2.61	3.03	3.42
07	30-min	1.19	1.45	1.69	2.06	2.39	2.69
07	15-min	0.87	1.06	1.23	1.50	1.74	1.97
07	10-min	0.68	0.83	0.96	1.17	1.35	1.53
07	5-min	0.39	0.47	0.55	0.67	0.77	0.87
08	10-day	5.45	6.61	7.57	8.99	10.09	11.04
08	5-day	4.32	5.37	6.26	7.64	8.78	9.99
08	72-hr	3.67	4.68	5.64	6.90	7.96	9.24
08	48-hr	3.39	4.30	5.06	6.28	7.35	8.60
08	24-hr	3.11	3.87	4.65	5.78	6.73	7.74
08	18-hr	2.92	3.64	4.37	5.43	6.33	7.28
08	12-hr	2.71	3.37	4.05	5.03	5.86	6.73
08	6-hr	2.33	2.90	3.49	4.34	5.05	5.80
08	3-hr	1.99	2.48	2.98	3.70	4.31	4.95
08	2-hr	1.80	2.24	2.70	3.35	3.90	4.49
08	1-hr	1.46	1.82	2.19	2.72	3.16	3.64
08	30-min	1.15	1.43	1.72	2.14	2.49	2.86
08	15-min	0.84	1.04	1.26	1.56	1.82	2.09
08	10-min	0.65	0.81	0.98	1.21	1.41	1.63
08	5-min	0.37	0.46	0.56	0.69	0.81	0.93
09	10-day	5.44	6.50	7.35	8.45	9.33	10.42
09	5-day	4.31	5.45	6.32	7.60	8.69	9.95
09	72-hr	3.79	4.87	5.74	6.95	7.88	8.98

*section	duration	2-year	5-year	10-year	25-year	50- year	100-year
09	48-hr	3.50	4.46	5.20	6.35	7.32	8.40
09	24-hr	3.14	4.03	4.67	5.67	6.58	7.59
09	18-hr	2.95	3.79	4.39	5.33	6.19	7.13
09	12-hr	2.73	3.51	4.06	4.93	5.72	6.60
09	6-hr	2.36	3.02	3.50	4.25	4.93	5.69
09	3-hr	2.01	2.58	2.99	3.63	4.21	4.86
09	2-hr	1.82	2.34	2.71	3.29	3.82	4.40
09	1-hr	1.48	1.89	2.19	2.66	3.09	3.57
09	30-min	1.16	1.49	1.73	2.10	2.43	2.81
09	15-min	0.85	1.09	1.26	1.53	1.78	2.05
09	10-min	0.66	0.85	0.98	1.19	1.38	1.59
09	5-min	0.38	0.48	0.56	0.68	0.79	0.91

Table 6: Sectional Mean Frequency Distribution for Storm Periods of 5 Minutes to 10 Days and Recurrent Intervals of 2 Months to 100 Years in Iowa.[7]

Rainfall (millimeters) for given recurrence interval T, return period in years.

*Sectional code (see Figure 3 Iowa map)

01-Northwest	04-West Central	07-Southwest
02-North Central	05-Central	08-South Central
03-Northeast	06-East Central	09-Southeast

*section	duration	2-year	5-year	10-year	25-year	50- year	100-year
01	10-day	122.17	148.32	170.18	203.71	231.39	261.87
01	5-day	95.76	118.87	137.92	167.89	193.04	222.25
01	72-hr	84.58	106.93	126.75	154.18	180.85	209.04
01	48-hr	76.45	96.77	114.81	142.24	165.86	191.01
01	24-hr	69.85	88.90	105.16	129.79	151.64	175.77
01	18-hr	65.79	83.57	98.81	121.92	142.49	165.10
01	12-hr	60.71	77.47	91.44	113.03	131.83	152.91
01	6-hr	52.32	65.55	78.99	97.28	113.79	131.83
01	3-hr	44.70	56.90	67.31	83.06	97.03	112.52
01	2-hr	40.39	51.56	60.96	75.18	87.88	101.85
01	1-hr	32.77	41.66	49.53	60.96	71.37	82.55
01	30-min	25.91	33.02	38.86	48.01	56.13	65.02
01	15-min	18.80	24.13	28.45	35.05	40.89	47.50
01	10-min	14.73	18.54	22.10	27.18	31.75	36.83
01	5-min	8.4	10.67	12.70	15.49	18.29	21.08
02	10-day	128.02	159.00	185.93	226.82	263.40	289.56
02	5-day	104.90	128.27	147.32	177.80	203.96	235.71
02	72-hr	89.66	113.03	130.81	160.78	185.42	210.82
02	48-hr	83.82	104.39	121.41	147.32	169.42	194.82
02	24-hr	75.69	94.49	111.25	135.38	155.96	179.58
02	18-hr	71.12	88.90	104.65	127.25	146.56	168.91
02	12-hr	65.79	82.30	96.52	117.86	135.64	156.21
02	6-hr	56.90	70.87	83.57	101.60	117.09	134.62
02	3-hr	48.51	60.45	71.12	86.61	99.82	114.81
02	2-hr	43.94	54.86	64.52	78.49	90.42	104.14
02	1-hr	35.56	44.45	52.32	63.75	73.41	84.33
02	30-min	27.94	35.05	41.15	50.04	57.66	66.55
02	15-min	20.32	25.40	29.97	36.58	42.16	48.51
02	10-min	16.00	19.81	23.37	28.45	32.77	37.59
02	5-min	9.14	11.43	13.46	16.26	18.80	21.59
03	10-day	128.02	156.72	179.58	210.57	233.68	258.83
03	5-day	100.08	123.44	143.23	173.74	196.85	222.76

[7] Huff, Floyd .A. & Angel, James R. *Rainfall Frequency Atlas of the Midwest.* Bulletin 71, 1992.

*section	duration	2-year	5-year	10-year	25-year	50- year	100-year
03	72-hr	87.38	109.98	130.56	157.23	177.80	199.14
03	48-hr	81.28	102.11	119.13	133.60	161.04	180.09
03	24-hr	73.91	93.22	109.47	129.79	145.54	161.54
03	18-hr	69.60	87.63	102.87	121.92	136.91	151.89
03	12-hr	64.26	81.03	95.25	113.03	126.75	140.46
03	6-hr	55.37	69.85	82.04	97.28	109.22	121.16
03	3-hr	47.24	59.69	70.10	83.06	93.22	103.38
03	2-hr	42.93	54.10	63.50	75.18	84.33	93.73
03	1-hr	34.80	43.69	51.56	60.96	68.33	75.95
03	30-min	27.43	34.54	40.39	48.01	53.85	59.69
03	15-min	20.07	25.15	29.46	35.05	39.37	43.69
03	10-min	15.49	19.56	23.11	27.18	30.48	34.04
03	5-min	8.89	11.18	13.21	15.49	17.35	19.30
04	10-day	132.59	160.27	181.86	209.30	233.93	260.86
04	5-day	103.12	125.48	145.80	178.82	206.50	235.46
04	72-hr	89.15	111.00	130.30	159.51	184.40	214.88
04	48-hr	80.26	100.84	119.63	148.84	172.97	198.63
04	24-hr	74.68	92.46	109.22	133.86	154.43	177.80
04	18-hr	70.10	86.87	102.62	125.73	133.86	167.13
04	12-hr	65.02	80.52	95.00	116.33	134.37	154.69
04	6-hr	55.88	69.34	82.04	100.33	115.82	133.35
04	3-hr	47.75	59.18	69.85	85.60	98.81	113.79
04	2-hr	43.43	53.59	63.25	77.72	89.66	103.12
04	1-hr	35.05	43.43	51.31	62.99	72.64	83.57
04	30-min	27.69	34.29	40.39	49.53	57.15	65.79
04	15-min	20.07	24.89	29.46	36.07	41.66	48.01
04	10-min	15.75	19.30	22.86	28.19	32.51	37.34
04	5-min	8.89	11.18	13.21	16.00	18.54	21.34
05	10-day	132.08	157.99	183.39	218.69	245.36	276.35
05	5-day	102.87	125.48	145.29	175.77	202.69	233.17
05	72-hr	88.14	112.01	131.06	157.99	179.32	206.25
05	48-hr	79.50	99.82	118.62	146.05	165.61	186.18
05	24-hr	73.91	92.46	108.46	130.81	149.10	167.89
05	18-hr	69.60	86.87	101.85	122.94	140.21	157.73
05	12-hr	64.26	80.52	94.23	113.79	129.79	146.05
05	6-hr	55.37	69.34	81.28	98.04	111.76	125.98
05	3-hr	47.24	59.18	69.34	83.82	95.50	107.44
05	2-hr	42.93	53.59	62.99	75.95	86.36	97.28
05	1-hr	34.80	43.43	51.05	61.47	70.10	78.99
05	30-min	27.43	34.29	40.13	48.51	55.12	62.23
05	15-min	20.07	24.89	29.21	35.31	40.13	45.21
05	10-min	15.49	19.30	22.86	27.43	31.24	35.31
05	5-min	8.89	11.18	12.95	15.75	17.78	20.07
06	10-day	132.33	159.26	180.85	209.55	235.46	262.89

*section	duration	2-year	5-year	10-year	25-year	50- year	100-year
06	5-day	104.65	124.21	142.49	170.18	196.85	228.60
06	72-hr	91.19	115.06	134.87	163.07	186.69	213.87
06	48-hr	81.53	105.41	128.27	152.91	174.50	198.88
06	24-hr	77.72	97.54	112.78	137.67	158.75	181.10
06	18-hr	73.15	91.69	105.92	129.29	149.35	170.18
06	12-hr	67.56	84.84	98.04	119.89	138.18	157.48
06	6-hr	58.42	73.15	84.58	103.38	119.13	135.89
06	3-hr	49.78	62.48	72.14	95.00	101.60	115.82
06	2-hr	44.96	56.64	65.53	79.76	91.95	105.16
06	1-hr	36.58	45.72	53.09	64.77	74.68	85.09
06	30-min	28.70	36.07	41.66	51.05	58.67	67.06
06	15-min	21.08	26.42	30.48	37.08	42.93	49.02
06	10-min	16.26	20.57	23.62	28.96	33.27	38.10
06	5-min	9.40	11.68	13.46	16.51	19.05	21.84
07	10-day	138.94	166.12	191.26	228.60	260.35	296.16
07	5-day	108.20	134.62	157.48	192.79	221.23	250.44
07	72-hr	97.79	121.67	141.22	172.21	198.12	228.35
07	48-hr	89.66	111.25	129.79	157.23	180.09	204.22
07	24-hr	81.79	99.82	116.08	141.22	163.83	184.91
07	18-hr	76.96	93.73	109.22	132.84	153.92	173.74
07	12-hr	71.12	86.87	101.09	113.79	142.49	160.78
07	6-hr	61.21	74.93	87.12	105.92	122.94	138.68
07	3-hr	52.32	64.01	74.17	90.42	104.90	118.36
07	2-hr	47.50	57.91	67.31	81.79	95.00	107.19
07	1-hr	38.35	46.99	54.61	66.79	76.96	86.87
07	30-min	30.23	36.83	42.93	52.32	60.71	68.33
07	15-min	22.10	26.92	31.24	38.10	44.20	50.04
07	10-min	17.27	21.08	24.38	29.72	34.29	38.86
07	5-min	9.90	11.94	13.97	17.02	19.56	22.10
08	10-day	138.43	167.89	192.28	228.35	256.29	280.42
08	5-day	109.73	136.40	159.00	194.06	223.01	253.75
08	72-hr	93.22	118.87	143.26	175.26	202.18	234.70
08	48-hr	86.11	109.22	128.52	159.51	186.69	218.44
08	24-hr	78.99	98.30	118.11	146.81	170.94	196.60
08	18-hr	74.17	92.46	111.00	137.92	160.78	184.91
08	12-hr	68.83	85.60	102.87	127.76	148.84	170.94
08	6-hr	59.18	73.66	88.65	110.24	128.27	147.32
08	3-hr	50.55	62.99	75.69	93.98	109.47	125.73
08	2-hr	45.72	56.90	68.58	85.09	99.06	114.05
08	1-hr	37.08	46.23	55.63	69.09	80.26	92.46
08	30-min	29.21	36.32	43.69	54.36	63.25	72.64
08	15-min	21.34	23.42	32.00	39.62	46.23	53.09
08	10-min	16.51	20.57	24.89	30.73	35.81	41.40
08	5-min	9.40	11.68	14.22	17.53	20.57	23.62

*section	duration	2-year	5-year	10-year	25-year	50- year	100-year
09	10-day	138.18	165.10	186.69	214.63	239.98	264.67
09	5-day	109.47	138.43	160.53	193.04	220.73	252.73
09	72-hr	96.27	123.70	145.80	176.53	200.15	228.09
09	48-hr	88.90	113.28	132.08	161.29	185.93	213.36
09	24-hr	79.76	102.36	118.62	144.02	167.13	192.79
09	18-hr	74.93	96.27	111.51	135.38	157.23	181.10
09	12-hr	69.34	89.15	103.12	125.22	145.29	167.64
09	6-hr	59.94	76.71	88.90	107.95	125.22	144.53
09	3-hr	51.05	65.53	75.95	92.20	106.93	123.44
09	2-hr	46.23	59.44	68.83	83.57	97.03	111.76
09	1-hr	37.59	48.01	55.63	67.56	78.49	90.68
09	30-min	29.46	37.85	43.94	53.34	61.72	71.37
09	15-min	21.59	27.69	32.00	38.86	45.21	52.07
09	10-min	16.76	21.59	24.89	30.23	35.05	40.39
09	5-min	9.65	12.19	14.22	17.27	20.07	23.11

Example 4

Determine the rainfall intensity I (in/hr) in Des Moines, Iowa with a recurrence interval T = 25 years and storm duration of T_c = 30 minutes.

English units

From Figure 5, Des Moines is in Sectional Code 05-Central

From Table 5: I = 1.91 inches per 30 minutes

$$I = \frac{1.91 in/\min}{30\min} \times 60\min/hr = 3.8 in/hr$$

Metric units

From Figure 5, Des Moines is in Sectional Code 05-Central

From Table 6: I = 48.51 mm per 30 minutes

$$I = \frac{48.51 mm/\min}{30\min} \times 60\min/hr = 97.02 mm/hr$$